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MAINTENANCE ANALYSIS OF A BUTT THIMBLE REMOVAL STATION IN ALUMINUM PLANT

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ABSTRACT

The paper presents maintenance analysis of a specific subsystem with two standby units called Butt Thimble Removal Press 1 & Butt Thimble Removal Press II, of an aluminum plant. Since the subsystem reliability contribute to the entire plant performance and functionality, it becomes important to assess the reliability of the subsystems as well. Six years' of data pertaining to failures, repairs and various cost associated with the system are collected for the purpose, and various rates and costs are also estimated from the data. Measures of subsystem effectiveness such as mean time to subsystem failure, availability of the subsystem, busy period analysis, and expected number of visits by the repairman to repair are estimated numerically by using Semi-Markov processes and regenerative point techniques.

Key words: reliability, failure rate, repair rate, semi Markov process, regenerative point.

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NOTATIONS AND SYMBOLS

$g_i(t), G_i(t)$	$p.d.f$ and $c.d.f$ of repair time of the station i
q_{ij}, Q_{ij}	Probability density function $(p.d.f)$, cumulative distribution function $(c.d.f)$ from a regenerative state i to a regenerative state j or the failed state without visiting any other non-regenerative state$(0, t]$.
p_{ij}	Probability of transition from a regenerative state i to a regenerative state j or to failed state in $(0, t]$.
S_i	State i.
λ_i	Failure rate of i^{th}component.
α_i	Repair rate of i^{th} component.
$*/LT$	Symbol for a Laplace Transform
$**/LST$	Symbol of a Lablace-Steiltjes transform
m_{ij}	The unconditional mean time taken to transit to any regenerative state from the epoch of entery into regenerative state j.
μ_i	Mean sojourn time in the regenerative state i before transiting to any other state.
©	Laplace convolution
Ⓢ	Steiltjes convolution
$\phi_i(t)$	Cumulative distribution function $(c.d.f)$ of the first passage time from a regenerative state i to a failed state
$M_i(t)$	The probability that the subsystem initially up in regenerative state i, is up at a time t without going to any regenerative state
$A_i(t)$	The probability of the unit entering into upstate at instant t, giving that the unit entered in regenerative state i at $t = 0$
$B_i(t)$	Probability that the repairman is busy in inspection of instant t, given that the system entered regenerative state i at $t = 0$
$V_i(t)$	Expected number of visits of the repairman, given that the subsystem entered regenerative state i at $t = 0$
$W_i(t)$	Probability that that the repairman is busy in regenerative state i at time t without passing any other regenerative state.

1. INTRODUCTION

Many researchers have spent a great deal of efforts in analyzing complex industrial systems from reliability perspective. A modeling approach using probabilistic concept play an important role in predicting and understanding the system behavior prior to its implementation, and is also useful in real case analysis of systems using the past data. Gopalan et al. [1] analysed a one unit repairable system subject to online preventive maintenance. Singh et al. [2] dealt with a two unit warm standby system with accident and various types of repair. Tuteja et al. [3]-[5] worked for two-units system with regular repairman who is not always available, system with perfect repair at partial failure or complete failure mode, and the profit evaluation of a two-units cold standby system with tiredness and two types of repairmen. Rizwan et al. [6]-[12] analyzed cold and hot standby systems with single-unit and two-units under different failure and repair situations and the some important reliability indices are obtained along with the cost benefit analysis of the systems. Mathew et al. [13]-[19] extensively analyzed the continuous casting plant and studied the variations under different operating conditions of the plant. Detailed analysis was reported for desalination plant by Padmavathi et al. [20] with online repair under emergency shutdowns, Rizwan et al. [21] with repair/maintenance strategy on first come first served basis, Padmavathi et al. [22]-[26] continued on desalination plant with priority for repair over maintenance, comparative analysis between the plant models, analysis under major and minor failures consideration, analysis by prioritizing repair over maintenance under major / minor failures, and comparative analysis between the plant models portraying two operating conditions of the plant as to which model is better than the other. The methodology was further extended for various industrial systems analyses by Gupta and Gupta [27] with post inspection concept, Ram et al. [28] waiting repair strategy, Malhotra and Taneja [29] both units operative on demand, Niwas et al. [30] obtained mean time to system failure and profit of a single unit system with inspection for feasibility of repair beyond warranty. Later, Rizwan et al. [31]-[33] focused on waste water treatment plant & anaerobic batch reactor and reliability indices of interest were obtained in order to assess the plant/reactor performance. Taj et al. [34]-[36] analyzed a cable plant for under different operating conditions and obtained various reliability indices of interest. Yaqoob et al. [37]-[38] discussed the reliability analysis of a particular subsystem of the plant & further analysed the complete rodding anode plant with eight stations in an aluminum industry. However, unlike other stations having single unit; station number 2 has two units operating with standby arrangement and hence etablishes the reason for analysing this operating situation seperately.

Thus, the plant as mentioned in [37]-[38] has been reconsidered for this purpose, and the analysis of station 2 called Butt Thimble Removal station has been carried out seperately. This station has two units viz., Butt Thimble Removal Press 1 & Butt Thimble Removal Press II, operating with standby arrangement. Six years maintenance data on component failures, repairs and various associated costs are collected from the maintenance record. Failure and repair rates with respect to maintenances are estimated from the data. The plant has eight stations viz., butt shot blast station 1, butt & thimble removal press station 2 with standby arrangement, combined btp (butt & thimble press) station 3, stub straighten station 4, stub shot blast station 5, stub coating and drying station 6, casting station 7, and anode rod inspection station 8. The plant operates round the clock, and failure in any of the stations impacts the plant to a complete shutdown situation. Reliability results at this level could be useful measures in gauging and comparing the entire plant operational effectiveness. The state transitions of the subsystem are shown in Table I. Semi-Markov process and regenerative point techniques are used in this analysis. Outcome of the subsystem analysis is measured in terms of mean time to system failure, availability of the subsystem, expected busy period of the repairman, and expected number of visits for repair.

2. DESCRIPTION OF THE SUBSYSTEM

The subsystem transition states are as the following:

State S_0: Operative state.

State S_1: Operative state in which the 1st component of the station is under repair and 2nd component is operative.

State S_2: Failed state in which both components of the station is under repair.

The subsystem regenerates and works as good as new after every maintenance preformed. Table I shows the transition rates from state S_i to S_j. 0 denotes for no transition to the mentioned state. Failure rates are exponential whereas the repair rates are taken as general.

Table 1 Transition states of the subsystem

S_i \ S_j	S_0	S_1	S_2
S_0	0	λ_1	0
S_1	$g_1(t)$	0	λ_2
S_2	0	$g_2(t)$	0

- All necessary maintenances are off-line which means plant need to be in switch-off mode.
- Maintenances need to be addressed on requirement by a single repairman.
- Other than failures which are exponentially distributed all distributions are general.

Table 2 shows the estimated values of repair/failure rates for the subsystem from the maintenance data of the plant.

Table 2 Estimated values for the subsystem OMR (Omani Rials)

S. No.	Failure Rate	Estimated value	Repair Rate	Estimated value	Average cost rate
1	λ_1	0.04117	α_1	0.18873	609 OMR
2	λ_2	0.03469	α_2	0.19140	489 OMR

3. TRANSITION PROBABILITIES AND MEAN SOJOURN TIMES

State S_0 and S_1 the regenerative states where S_2 is the failure state in the subsystem. The transition probabilities from S_i to S_j be given by the following equations:

$dQ_{01} = \lambda_1 e^{-\lambda_1 t}\, dt$
$dQ_{12} = \lambda_2 e^{-\lambda_2 t}\overline{G_1(t)}$
$dQ_{10} = g_1(t) e^{-\lambda_2 t}\, dt$
$dQ_{21} = g_2(t)\, dt$

The non-zero elements $p_{ij} = \lim_{s\to 0} q_{ij}{}^{*}(s)$ are given below:

$p_{01} = 1$
$p_{12} = \frac{\lambda_2}{\alpha_1+\lambda_2}$
$p_{10} = \frac{\alpha_1}{\alpha_1+\lambda_2}$
$p_{21} = 1$

By these transition probabilities it can be verified that:

$p_{01} = p_{21} = 1$
$p_{10} + p_{12} = 1$

The mean sojourn time $\left(\mu_i = \int_0^\infty t dQ_{ij}(t)\right)$ in regenerative state i is defined as the time of stay in that state before transition to any other state. So, if T denotes the sojourn time in the regenerative state i then:

$\mu_0 = \int_0^\infty t dQ_{01}(t) = \frac{1}{\lambda_1}$
$\mu_1 = \int_0^\infty t dQ_{10}(t) + \int_0^\infty t dQ_{12}(t) = \frac{1}{\alpha_1+\lambda_2}$
$\mu_2 = \int_0^\infty t dQ_{21}(t) = \frac{1}{\alpha_2}$

The unconditional mean time taken $\left(m_{ij} = \lim_{s\to 0} -\frac{d}{ds}\left(q_{ij}{}^{*}(s)\right)\right)$ by the system to transit for any state j when it has taken from epoch of entrance into regenerative state i is mathematically stated as:

Thus,

$m_{01} = \mu_0$
$m_{10} + m_{12} = \mu_1$
$m_{21} = \mu_2$

4. MATHEMATICAL ANALYSIS

4.1. Mean Time to System Failure

Let $\phi_i(t)$ be the $c.d.f$ of the first passage time from regenerative state i to a failed state. By probabilistic arguments, the following recursive relation for $\phi_i(t)$ are obtained:

$\phi_0(t) = Q_{01}(t) \circledS \phi_1(t)$

$\phi_1(t) = Q_{10}(t) \circledS \phi_0(t) + Q_{12}(t)$

On taking Laplace Stieltjes transform of equations (17) & (18) and solving for $\phi_0{}^{**}(s)$, the mean time to system failure in steady state is given by:

MTSF = $\lim_{s\to 0} \frac{1-\phi_0{}^{**}(s)}{s} = \frac{D\acute{(0)}-N\acute{(0)}}{D(0)} = \frac{N}{D}$

Where,

$N = 1 + m_{12} - p_{10} + m_{01}p_{12}$

$D = p_{12}$

4.2. Availability Analysis of the Subsystem

$A_i(t)$ is the probability of the unit entering into the upstate at an instant , given that the unit entered in regenerative state i at $t = 0$. The following recursive relations are obtained for $A_i(t)$:

$A_0(t) = M_0(t) + q_{01}(t)© A_1(t)$

$A_1(t) = M_1(t) + q_{10}(t)© A_0(t) + q_{12}(t)© A_2(t)$

$A_2(t) = q_{21}(t)© A_1(t)$

Where

$M_0(t) = e^{-\lambda_1 t}$ & $M_1(t) = \overline{G_1(t)}\, e^{-\lambda_2 t}$

On taking Laplace transforms of the equations (20) to (22) and solving them for $A_0^*(s)$, the availability of the subsystem in steady state is given by:

$$A_0 = \lim_{s\to 0} s A_0^*(s) = \frac{N_1}{D_1}$$

Where,

$N_1 = \mu_0 + \mu_1 - \mu_0 p_{12}$

$D_1 = m_{10} + m_{12} + \mu_0 p_{10} + \mu_2 p_{12}$ Or $D_1 = \mu_1 + \mu_0 p_{10} + \mu_2 p_{12}$

4.3. Busy Period Analysis of Repairman

Using the probabilistic arguments, we have the following relations for $B_i(t)$ as probability that the repairman is busy for repair at instant t, given that unit entered in regenerative state i at $t = 0$, the following recursive relations are obtained for $B_i(t)$:

$B_0(t) = q_{01}© B_1(t)$

$B_1(t) = W_1(t) + q_{10}(t)© B_0(t) + q_{12}(t)© B_2(t)$

$B_2(t) = W_2(t) + q_{21}(t)© B_1(t)$

Where, $W_1(t) = \overline{G_1(t)}\, e^{-\lambda_2 t}$ & $W_2(t) = \overline{G_2(t)}$

On taking the Laplace transforms of the equations (24) to (26), the expected busy period of the repairman in steady state is given by:

$$B_0 = \lim_{s\to 0} s B_0^*(s) = \frac{N_2}{D_1}$$

Where,

$N_2 = \mu_1 + \mu_2 p_{12}$

D_1 is already specified

4.4. Expected Number of Visits by the Repairman for Repairs

Let $V_i(t)$ be defined as the expected number of visits for repairs in $(0, t]$, given that the system initially starts from the regenerative state i. Using the probabilistic arguments, the following recursive relations are obtained for $V_i(t)$:

$V_0(t) = Q_{01}(t) \circledS V_1(t)$

$V_1(t) = Q_{10}(t) \circledS V_0(t) + Q_{12}(t) \circledS \left(1 + V_2(t)\right)$

$V_2(t) = Q_{21}(t) \circledS V_1(t)$

On taking Laplace Stieltje's transform of equations (28) to (30), the number of visits by the repairman in steady state is given by:

$$V_0 = \lim_{s \to 0} s V_0^{**}(s) = \frac{N(0)}{\acute{D}(0)} = \frac{N_3}{D_1}$$

Where,

$N_3 = p_{12}$

D_1 is already specified

5. PARTICULAR CASE

For this particular case, the following have been considered:

$g_1(t) = \alpha_1 e^{-\alpha_1 t}$ & $g_2(t) = \alpha_2 e^{-\alpha_2 t}$, where $\alpha_1$and α_2 are estimated from the data and mentioned in table II

Using the data as summarized in table II, the expressions of reliability measures as in (19), (23), (27) and (31), the following values of subsystem effectiveness are obtained:

Mean time to system failure = 28.7654 hrs.

Availability = 0.82785

Busy period of repairman = 0.204885

Expected number visits by the repairman for repair = 0.00601692

6. CONCLUSIONS

Mean time to system failure is about 30 hours which shows, there is a failure almost every 30 hours. Other measures could further be improved by adopting better maintenance practices. As a future direction, the analysis could further be explored for other complex operating situations of the plant.

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